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Abstract

The objective of this study was to define the risk of hearing loss among US military members in relation to their deployment experiences. Data were drawn from the Millennium Cohort Study. Self-reported data and objective military service data were used to assess exposures and outcomes. Among all 48,540 participants, 7.5% self-reported new-onset hearing loss. Self-reported hearing loss showed moderate to substantial agreement (k = 0.57-0.69) with objective audiometric measures. New-onset hearing loss was associated with combat deployment (adjusted odds ratio [AOR] = 1.63, 95% confidence interval [CI] = 1.49-1.77), as well as male sex and older age. Among deployers, new-onset hearing loss was also associated with proximity to improvised explosive devices (AOR = 2.10, 95% CI = 1.62-2.73) and with experiencing a combat-related head injury (AOR = 6.88, 95% CI = 3.77-12.54). These findings have implications for health care and disability planning, as well as for prevention programs.

Keywords: Combat disorders, hearing loss, military personnel

Introduction

The association between US military service and hearing loss continues to receive significant attention, especially in light of recently completed and ongoing combat deployments in Iraq and Afghanistan.[1-4] Nearly one-half million US veterans are currently receiving over $1 billion annually in Department of Veterans Affairs (VA) compensation for hearing loss.[5] As a result, hearing loss is the most common service-connected disability.[6] Traditionally, most hearing loss associated with military service has been caused by high intensity and/or impulse noise.[1] In recent years, an increasing number of US service members have hearing loss as a result of being in proximity to the detonation of explosive devices in the Iraq and Afghanistan operations.[7] For example, deployment has been observed to increase the risk of hearing loss, with 71% of soldiers returning from Iraq or Afghanistan reporting exposure to loud noise, and more than 15% of returnees reporting ringing in their ears.[8]

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Hearing loss is a significant health and readiness issue for the US military since afflicted personnel exposed to hazardous noise are more likely to suffer additional hearing damage,[9] and service members with hearing loss attrite at a higher rate from military service than those with normal hearing.[10] Yet, population-based studies to describe the association between deployment and hearing loss are limited. A study of US Army soldiers who visited audiology clinics noted that hearing loss was identified in 68.6% of post-deployment diagnoses and 4.0% of non-deployment-related diagnoses.[11] One population-based study that utilized a number of International Classification of Diseases, 9th Revision, Clinical Modification diagnostic codes for hearing loss found annual incidence rates between 19.3 and 22.2/1000; however, the study did not include deployment as an exposure and was limited to active-duty service members.[1] Patient-based studies have reported hearing loss in 15% of patients with tympanic membrane perforation admitted to Brooke Army Medical Center,[7] and 19% of patients admitted to a rehabilitation center with comorbid traumatic brain injury.[12]

The present study uses data from the Millennium Cohort Study, the largest prospective study of military personnel to

date, which follows participants to evaluate whether military service exposures are associated with long-term health outcomes. Given the large sample of deployed participants in the Millennium Cohort, this study offers a unique opportunity to prospectively evaluate the association between military deployment and hearing loss among members of all service branches including active duty, Reserve, and National Guard members. The objective of this study was to examine the association between military deployment and subsequent hearing loss.

Methods

The Millennium Cohort Study, launched in 2001, is a longitudinal cohort study designed to assess the effects of US military service on the health of participants over a follow-up period of at least 21 years. The study utilizes a comprehensive questionnaire, completed approximately every 3 years by participants via mail and a secure Internet system. A random sample of US military members from all service branches and components who were on active rosters as of October 2000 was selected for the first enrollment panel. This panel was enrolled from 2001 to 2003 (n = 77,047, 36.0% response rate) and was oversampled for women, Reserve/Guard personnel, and individuals deployed to southwest Asia, Bosnia, or Kosovo from 1998 to 2000. Additional details on study methodology and response rates have been published elsewhere.[13-15] The eligible population for these analyses included participants from the first enrollment panel who completed at least one follow-up questionnaire (first follow-up from 2004 to 2006 or second follow-up from 2007 to 2008) and did not self-report significant hearing loss at baseline (n = 57,593). Participants were excluded from these analyses if they deployed before baseline or completed any of their assessments while deployed. Additionally, participants were excluded if they were missing relevant outcome or covariate data. The final study population included 48,540 participants. This study was approved by the institutional review board at the Naval Health Research Center, and all Millennium Cohort members are voluntary participants.

Data for this study were obtained from the Millennium Cohort Study questionnaire as well as electronic military records. The questionnaire collects self-reported demographic, health, behavioral, and exposure data, such as hearing loss, tobacco use, and combat-related experiences. Electronic military records, including age, sex, service branch, service component, military occupation, education level, marital status, military separation status, and deployment dates, were provided by the Defense Manpower Data Center. When available, self-reported data were used to supplement electronic data from personnel records to minimize missing data. In addition, this study utilized audiometric data, maintained by the Defense Occupational and Environmental Health Readiness System-Hearing Conservation data repository,[16] when available, to validate self-reported hearing loss data. Military personnel in a hearing conservation program have audiometric testing at least annually. All military personnel have audiometric testing, at a minimum, at the time of entrance, at the time of discharge, and to assess readiness prior to any deployment or other hazardous duty.

Exposures

Combat deployment, the exposure of interest for the primary analyses, was defined as having deployed to Operation Iraqi Freedom or Operation Enduring Freedom or in support of these conflicts and having personally:

1. Witnessed a death due to war, disaster, or tragic event;
2. Witnessed instances of physical abuse;
3. Been exposed to dead or decomposing bodies;
4. Been exposed to maimed soldiers or civilians; or
5. Been exposed to prisoners of war or refugees.

Those who had deployed with combat exposures were compared with those who had deployed without combat exposures and with those who had not deployed.

Secondary analyses examined a subset of the study population who had deployed and completed the 2007-2008 Millennium Cohort questionnaire that included questions regarding exposure to improvised explosive device (IED) blast- and combat-related head trauma. These secondary analyses assessed hearing loss in relation to blast and combat-related head trauma.

Additional variables, including self-reported smoking status, and exposure to pesticides, chemicals, and occupations requiring the use of personal protective equipment (PPE), were included in all models. Chemical exposure was defined as self-reported routine skin contact with paint and/or solvents and/or other hazardous substances during the past 3 years. Pesticide exposure was defined as self-reported exposure to pesticides, including creams, sprays, or uniform treatments, or pesticides applied in the environment or around living facilities, during the past 3 years. Occupations requiring PPE were defined as occupational hazards requiring protective equipment, such as respirators or hearing protection during the past 3 years. Smokers were defined as those who reported smoking at least 100 cigarettes in their lifetime. Past smokers were differentiated from current smokers if they reported to have successfully quit smoking. Never-smokers were those who had never smoked 100 cigarettes in their lifetime.

Outcomes

Hearing loss was assessed using the Millennium cohort questionnaire, which includes the baseline question: "Has your doctor or other health professional ever told you that you have any of the following conditions? with the response being significant hearing loss." The question was modified in

follow-up questionnaires to describe new hearing loss over "the last 3 years," based on the study design of re-surveying participants at approximately 3-year intervals. Participants who did not self-report hearing loss at baseline, but later positively endorsed self-reported hearing loss during a follow-up survey, were classified as having new-onset self-reported hearing loss.

Objective audiometric data were dichotomized using the VA standards for impaired hearing.[16] For VA purposes, impaired hearing is considered a disability when the audiometric hearing threshold in any of the frequencies (500, 1000, 2000, 3000, or 4000 Hz) is 40 dB or greater; or when the auditory thresholds for at least three of these frequencies are 26 dB or greater. Note that the VA definition also includes those who have speech recognition scores <94%, but the audiometric database did not contain this additional information.

Statistical analyses

Initial descriptive analyses included frequencies, percentages, and Chi-square tests to describe the variables within the population. Multivariable logistic regression was used for the primary model to determine the odds of new-onset self-reported hearing loss in relation to combat deployment, while adjusting for all covariates noted previously. All variables were assessed at baseline except for military separation and deployment experiences, which were assessed throughout the study period. Secondary analyses using multivariable logistic regression included an assessment of the relations between hearing loss and exposure to blasts and combat-related head trauma among a deployed subset of this study group who had completed a baseline survey in 2001, deployed between 2004 and 2007, and completed the 2007 survey. Multicollinearity was assessed using a variance inflation factor of 4 or greater to identify potentially collinear variables.

Validation of self-reported hearing loss was evaluated by comparing Millennium Cohort survey data and objective audiometric data. VA criteria for hearing impairment were applied as described previously, to define audiometrically "normal" or "abnormal" hearing. Each self-report of hearing loss (yes/no) was evaluated based on the time stamp of the survey and the timing of available audiometric data. Self-report of "yes" hearing loss was considered valid if any preceding audiogram was abnormal. Self-report of "yes" hearing loss was considered invalid if any subsequent audiogram was normal. In addition, those without a preceding validating test who also lacked a subsequent invalidating test and had all abnormal audiograms after self-report were considered to have valid hearing loss. Consistent criteria were applied to validate the absence of hearing loss. Self-report of "no" hearing loss was considered valid if any subsequent audiogram was normal. Self-report of "no" hearing loss was considered invalid if any previous audiogram was abnormal. In addition, those without a subsequent validating test, who also lacked a previous invalidating test, and had all normal audiograms prior to self-report, were considered to have valid absence of hearing loss. All self-reports were independently assessed, and the degree of nonrandom agreement between the audiometric data and self-reported data was calculated using the kappa statistic.[17] A kappa value between 0.6 and 0.8 was considered substantial agreement, and a kappa value between 0.4 and 0.6 was considered moderate agreement.[18] In addition, a sensitivity analysis was conducted using multivariable logistic regression to examine the odds of self-reported new-onset hearing loss among only those subjects with a validated audiometric record.

Data management and statistical analyses were performed using SAS software, version 9.3 (SAS Institute, Inc., Cary, North Carolina).

Results

This study included 48,540 Millennium Cohort Study participants, of whom 3660 (7.5%) self-reported new-onset hearing loss during follow-up. Demographic, military, and behavioral characteristics for those who reported new-onset hearing loss, in comparison with those who reported no hearing loss during the study period, are shown in Table 1. In this comparison, all differences were statistically significant ($P < 0.001$) with the exception of service component.

Multivariable logistic regression was used to calculate adjusted odds ratios (AORs) for new-onset hearing loss [Table 2]. In this analysis, Millennium Cohort Study participants who were deployed with combat experience had increased odds (AOR = 1.63, 95% confidence interval [CI] = 1.49-1.77) of reporting new-onset hearing loss compared with those who were not deployed. In this adjusted model, male sex, being born before 1970 (compared with those born in 1980 or later), or being currently married were all demographic characteristics associated with increased odds of new-onset self-reported hearing loss. Conversely, those of black non-Hispanic race/ethnicity (compared with other race/ethnicity) were at decreased odds of new-onset self-reported hearing loss. Military-specific characteristics with increased odds of hearing loss were serving in the Army, Navy/Coast Guard, or Marines (compared with serving in the Air Force), reporting exposures to occupational hazards that required PPE (including hearing protection) or routine contact with chemicals, or exposure to pesticides. Conversely, officers, those serving in the Reserve/National Guard (compared with active duty), those serving as health care specialists (compared with functional support specialists), and those separated from the military had lower adjusted odds of reporting new-onset hearing loss. Finally, past or current smokers (compared with never smokers) had increased adjusted odds of reporting new-onset hearing loss.

Table 1: Distribution of demographic, military and behavioral characteristics of 48,540 Millennium Cohort participants in relation to hearing status

Characteristic	No hearing loss *n* = 44,880		New-onset hearing loss *n* = 3660		*P*
	n	Percentage	*n*	Percentage	
Sex					
Male	30,953	69.0	3163	86.4	<0.001
Female	13,927	31.0	497	13.6	
Birth cohort					
Pre1970	27,849	62.1	2729	74.6	<0.001
1970-1979	14,898	33.2	806	22.0	
1980+	2133	4.8	125	3.4	
Race/ethnicity					
White nonHispanic	31,122	69.3	2748	75.1	<0.001
Black nonHispanic	6215	13.9	296	8.1	
Other	7543	16.8	616	16.8	
Education					
Some college or less	31,553	70.3	2732	74.6	<0.001
Bachelor's or higher	13,327	29.7	928	25.4	
Marital status					
Currently married	28,698	63.9	2701	73.8	<0.001
Not currently married	16,182	36.1	959	26.2	
Military pay grade					
Enlisted	32,975	73.5	2840	77.6	<0.001
Officer	11,905	26.5	820	22.4	
Service component					
Active duty	24,617	54.9	2003	54.7	0.885
Reserve/National Guard	20,263	45.2	1657	45.3	
Branch of service					
Army	20,329	45.3	1955	53.4	<0.001
Air Force	14,070	31.4	855	23.4	
Navy/Coast Guard	8452	18.8	628	17.2	
Marine Corps	2029	4.5	222	6.1	
Occupational category					
Combat specialists	8393	18.7	881	24.1	<0.001
Electronic equipment repair	4044	9.0	299	8.2	
Health care specialists	5511	12.3	288	7.9	
Communications/intel	3222	7.2	244	6.7	
Other technical	1125	2.5	97	2.7	
Functional support/ admin	9829	21.9	645	17.6	
Electrical/mechanical equipment repair	5720	12.8	598	16.3	
Craft workers	1307	2.9	134	3.7	
Service and supply	3739	8.3	353	9.6	
Students, trainees, other	1990	4.4	121	3.3	
Deployment experience*					
Not deployed	29,970	66.8	2126	58.1	<0.001
Deployed without combat	7612	17.0	529	14.5	
Deployed with combat	7298	16.3	1005	27.5	
Exposed to occupational hazards requiring PPE					
No	21,945	48.9	1382	37.8	<0.001
Yes	22,935	51.1	2278	62.2	
Routine skin contact with chemicals					
No	33,769	75.2	2353	64.3	<0.001
Yes	11,111	24.8	1307	35.7	
Pesticide exposure					
No	29,640	66.0	1986	54.3	<0.001
Yes	15,240	34.0	1674	45.7	
Smoking					
Never smokers	26,311	58.6	1781	48.7	<0.001
Past smokers	11,618	25.9	1177	32.2	
Current smokers	6951	15.5	702	19.2	
Military separation					
No	33,819	75.4	2858	78.1	<0.001
Yes	11,061	24.7	802	21.9	
Proximity to IED blast†					
No	3007	76.5	169	54.0	<0.001
Yes	925	23.5	144	46.0	
Combat-related head trauma‡					
No	3899	99.2	292	93.3	<0.001
Yes	33	0.8	21	6.7	

*Deployment occurred after baseline, †Self-report of close proximity to an IED blast as reported on 2007 questionnaire among those whose first deployment occurred between their 2004 and 2007 Millennium Cohort follow-up questionnaire (*n* = 4245), ‡Self-report of combat-related head trauma as reported on 2007 questionnaire among those whose first deployment occurred between their 2004 and 2007 Millennium Cohort follow-up questionnaire (*n* = 4,245), IED = Improvised explosive device, PPE = Personal protective equipment

Results from the subanalysis indicated that among persons who deployed and completed the 2007-2008 questionnaire (*n* = 4245), 1069 reported proximity to a blast, of whom 144 (13.5%) reported new-onset hearing loss. Fifty-four deployers reported combat-related head trauma, of whom 21 (38.9%) reported new-onset hearing loss. Two separate logistic regression analyses that included all variables (except for deployment/combat experience) were performed on the data of the subset of participants who had been deployed during the study period, to assess the relations between combat-related head trauma or blast exposure and new-onset hearing loss [Table 3]. Participants who reported combat-related head trauma were more than 6 times as likely to report new-onset hearing loss (AOR = 6.88, 95% CI = 3.77-12.54). Similarly, participants who reported blast exposure were more than twice as likely to report new-onset hearing loss (AOR = 2.10, 95% CI = 1.62-2.73).

The audiometric validation procedure allowed for one audiometry record to correspond with one self-reported record from each survey time period. Among the 48,540 individuals included in this study, there were 63,481 self-reports of hearing status during the study period validated among 25,987 Millennium Cohort participants. There was moderate to substantial agreement between self-reported hearing and audiometric data at each survey cycle, with kappa values of 0.69 (95% CI = 0.67-0.71), 0.60 (95% CI = 0.58-0.62), and 0.57 (95% CI = 0.56-0.59) for the self-

Table 2: AOR of reporting new-onset hearing loss

Characteristic*	*n* = 48,540	
	AOR	95% CI
Deployment experience		
Not deployed	1.00	
Deployed without combat	0.98	0.89-1.09
Deployed with combat	1.63	1.49-1.77
Sex		
Female	1.00	
Male	2.02	1.82-2.25
Birth cohort		
1980 and later	1.00	
1970-1979	0.82	0.67-1.01
Before 1970	1.73	1.40-2.12
Race/ethnicity		
Other	1.00	
White nonHispanic	1.09	0.98-1.20
Black nonHispanic	0.63	0.54-0.73
Education		
Some college or less	1.00	
Bachelor's or higher	0.95	0.85-1.07
Marital status		
Not currently married	1.00	
Currently married	1.16	1.07-1.27
Military pay grade		
Enlisted	1.00	
Officer	0.72	0.63-0.82
Service component		
Active duty	1.00	
Reserve/National Guard	0.86	0.79-0.93
Branch of service		
Air Force	1.00	
Army	1.76	1.61-1.93
Navy/Coast Guard	1.31	1.17-1.46
Marine Corps	1.85	1.58-2.18
Occupational category		
Functional support specialists	1.00	
Combat specialists	1.11	0.99-1.25
Electronic equipment repair	0.91	0.78-1.06
Health care specialists	0.85	0.73-0.98
Communications/intelligence	0.94	0.81-1.10
Other technical	0.96	0.76-1.20
Electrical/mechanical equipment repair	1.05	0.92-1.19
Craft workers	1.06	0.87-1.30
Service and supply handlers	1.12	0.98-1.29
Students, trainees, other	0.91	0.74-1.12
Smoking		
Never smokers	1.00	
Past smokers	1.27	1.17-1.38
Current smokers	1.27	1.15-1.40
Exposed to occupational hazards requiring PPE		
No	1.00	
Yes	1.18	1.09-1.28
Routine skin contact with chemicals		
No	1.00	
Yes	1.21	1.11-1.31
Pesticide exposure		
No	1.00	
Yes	1.29	1.20-1.39
Military separation		
No	1.00	
Yes	0.81	0.74-0.89

*All characteristics shown are included in the multivariable model, AOR = Adjusted odds ratio, CI = Confidence interval, PPE = Personal protective equipment

Table 3: AOR of reporting new-onset hearing loss in relation to combat-related head trauma and exposure to IED blast among deployed service members

Characteristic*	*n* = 4245			
	AOR	95% CI	AOR	95% CI
IED				
No	1.00			
Yes	2.10	1.62-2.73		
Combat-related head trauma				
No			1.00	
Yes			6.88	(3.77-12.54)

*Adjusted for sex, birth year, education, marital status, race/ethnicity, smoking status, pay grade, service component, service branch, occupation, use of PPE, separation from the military and exposure to pesticides or chemicals, AOR = Adjusted odds ratio, CI = Confidence interval, PPE = Personal protective equipment, IED = Improvised explosive device

reported data from 2001, 2004, and 2007, respectively. The percent positive and percent negative agreement were also calculated for each year. The percent positive agreement for 2001, 2004, and 2007 were 83.0%, 56.9%, and 51.1%, respectively, while the percent negative agreement for 2001, 2004, and 2007 were 96.0%, 97.3%, and 97.7%, respectively.

Results from the sensitivity analysis examining new-onset hearing loss among only those subjects with a validated audiometric record indicated consistent findings for all measures of association and significance levels (data not shown).

Discussion

To our knowledge, this is the first large-scale prospective study of a military cohort to describe self-reported hearing loss after military deployment that was validated with audiometric data. In this study, we observed moderate to substantial agreement between self-reported hearing loss and hearing loss defined by audiometric data. Millennium Cohort participants who were deployed with combat experience had a 1.6-fold increased odds for reporting new-onset hearing loss compared with non-deployers. Furthermore, in analyses limited to deployed participants, being in close proximity to an explosive blast or experiencing head trauma were strongly associated with new-onset hearing loss. These findings quantify an important health risk faced by US service members who deploy to combat environments.

Individuals with the occupational code of "combat specialists" were 11% more likely to report hearing loss, but this association was not statistically significant. Given that combat experience was associated with a statistically significant increased risk for self-reported hearing loss, it would seem logical to observe the same for combat specialists. The apparent lack of an association may be partially attributable inherent limitations in the DoD Occupational Conversion Index. For example, some "combat specialists" do not actively participate in ground combat that includes discharging weapons.

Using a large military audiometric database to validate self-reported hearing loss was a novel component of these analyses. US military service represents one of the few occupations with a requirement for regular audiometric testing of its members, and the maintenance of clinical audiometric data in a large electronic data repository is a unique attribute of the military health care system.[19] It might have been assumed that study participants would not self-report hearing loss very accurately or consistently, especially in response to a single question on the survey. Hearing loss may be overreported when members learn they have to retake a hearing test for any reason; hearing loss may also be underreported when members fail to notice or acknowledge subtle changes in their hearing.[20] The results from this study suggest that negative reports of hearing loss have substantial accuracy, while positive reports of hearing loss have moderate accuracy, based on comparison with objective audiometric data that would meet VA disability criteria for hearing impairment.[16]

Finding that individuals who were deployed and had combat experiences were 1.6 times more likely to report new-onset hearing loss, compared with their nondeployed counterparts, appears to be a unique contribution to the epidemiologic study of hearing loss. One other study found an association between deployment and hearing loss, but the data were limited to an assessment of US Army soldiers.[11] Another interesting and important contribution of the current study was the finding that deployed individuals without combat experiences were not at increased risk for new-onset hearing loss compared with nondeployed personnel. This implies that much of the hearing loss attributable to the deployment is related to specific combat experiences rather than to deployment itself. Combat may include a significant amount of impulse noise, characterized as noise with a duration of <1 second and with peak levels 15 dB louder than background noise.[19] Sources of impulse noise include firing weapons or artillery, as well as detonation of explosive devices. A study conducted in Finland reported that combat and shooting exercises can reach peak noise levels of 180 dB,[20] and researchers at the US National Institute for Occupational Safety and Health have stated that, "firing a weapon poses a significant risk of noise-induced hearing loss, if hearing protection is not worn".[21] Impulse noise in addition to continuous noise exposure has been reported to be more damaging to hearing than continuous noise exposure alone.[22,23] Compounding the problem may be the challenge of wearing hearing protection during combat operations. A study conducted among Canadian armed forces found that ground combat troops were hesitant to use hearing protection because they felt it reduced detection of auditory warnings and reduced communication among the team members.[24] Although research is being conducted to develop appropriate hearing protection for combat, a 2009 study among US Army cadets found that most devices are lacking in performance and acceptance.[25] These findings suggest that additional research is needed to design hearing protection devices that will meet the needs of ground combat forces.

As expected, subgroup analyses of the deployed study participants revealed that the likelihood of reporting new-onset hearing loss was increased with exposures to both combat-related head trauma and proximity to an explosive blast. Participants reporting head trauma related to combat were over 6 times more likely to report new-onset hearing loss, whereas those reporting proximity to a blast were approximately twice as likely to report new-onset hearing loss. Since the question on blast exposure relates to "having an IED or booby trap explode near you," there could be some variability in how the word "near" is interpreted, and exposure at some distances may not have resulted in injury to the auditory system. We were not able to assess the nature of the blast, nor quantify proximity to the blast, use of hearing protection, or loss of consciousness. Combat-related head trauma is likely to include those exposed to blasts, as well as exposure to small arms fire, artillery, grenades, and physical assault. Besides the primary effects of blast overpressure, peripheral or central auditory system damage can occur from secondary effects (shrapnel and other blast-accelerated debris), and tertiary effects (body being thrown and impacting other objects). The most common types of blast-related injury involve middle and inner ear structures resulting in conductive, sensorineural, or mixed type of hearing loss. Pure sensorineural hearing loss is the predominant type occurring in blast-related traumatic brain injury and was reported to be nearly 60% in a study of inpatients at a VA rehabilitation unit.[26] A recent study among US Army soldiers reported low levels of referral to audiology clinics following indications of noise-induced hearing loss and head injury on post-deployment health assessments,[27] highlighting the importance of attention to these issues after any suspected exposure.

In addition to deployment, other key factors were associated with new-onset hearing loss in the multivariable analysis including male sex, increasing age, non-black race/ethnicity, tobacco use, exposure to other occupational hazards, contact with chemicals, and exposure to pesticides similar to previous reports.[1,5,28-31] The consistency of findings observed here with other published studies lends further credibility to the use of new-onset self-reported hearing loss as a valid

measure in this population. In possible contrast, one previous study found increased odds of hearing loss among adult Hispanics who were unmarried,[32] whereas in this study, married members were at increased odds for reporting new-onset hearing loss. No biologically plausible reason exists for the finding that married individuals were at increased risk for new-onset hearing loss in models that adjust for demographic variables. It may be that marriage was associated with other exposures that could not be assessed. It is also possible that this finding is due to correlation between marriage and age, and that birth-year cohorts incompletely adjusted for the age effect.

This study, as well as a previous study,[10] found an increased risk for hearing loss among active duty compared with Reserve/Guard members. Serving in the military is associated with increased risk for hearing loss,[33] and it is likely that serving in the Reserve/Guard means fewer hours of munitions-related noise exposure due to the non-continuous active-duty status of these US service members. Officers were at decreased odds for reporting new-onset hearing loss, as were members of the Air Force. These differences may reflect less hazardous noise exposures and/or increased compliance with hearing protection programs in these groups.

Observing that those who had separated from service were at lower odds for reporting new-onset hearing loss may appear counterintuitive. First, all members of the US military receive an audiogram prior to leaving the military, which would likely increase hearing loss diagnoses among those separating. Secondly, the literature suggests that those with hearing loss attrite from the military at a higher rate than those without hearing loss.[10] Given that the prevalence of hearing loss was found to be greater among military veterans compared with civilians,[33] it may be possible that this observation reflects the reduced risk for new-onset hearing loss associated with being a civilian in comparison with the increased risk associated with continued military service in this adjusted model.

There are a number of limitations to consider regarding this evaluation. The primary outcome was based on self-report in a health questionnaire. Audiometric testing data were available on approximately half of all participants. When available, audiometry data validated self-reported data. The validation scheme, while imperfect, assumed that normal hearing has the potential to become abnormal and that established abnormal hearing cannot return to normal, consistent with the physiology of noise-induced hearing loss. Several previous studies conducted in Australia, Brazil, and the United States of the accuracy of a single self-reported question on hearing loss reported sensitivities ranging from 0.71 to 0.78 and specificities from 0.56 to 0.76, compared with hearing impairment defined by audiometric testing.[34-36] These studies evaluated older subjects, hence results of their validation testing may not apply to this younger population. One investigation recruited construction workers who face occupational noise exposure, and with an average age of 42.8 years, this study population is perhaps more comparable to the Millennium Cohort participants;[37] this study reported sensitivities of 0.87-0.88 and specificities of 0.68-0.74 for detection of lower frequency hearing loss using a question that elicited a rating of hearing ability on a 1 (excellent) to 5 (poor) scale, with fair or poor ratings defined as a positive self-report of hearing loss, and lower kappa values (0.25-0.45) were reported. In our study, validation of self-report of past diagnosis compared with audiometric testing was much stronger. The degree of misclassification may, therefore, be smaller in our study, but undoubtedly some nondifferential misclassification remains that reduced the magnitude of observed associations. However, a consistent result found from the sensitivity analysis performed on validated subjects is reassuring.

There were a number of variables used in this analysis that could not be perfectly measured and may have introduced misclassification. We were not able to directly measure hazardous noise levels associated with combat, and had to rely on our imperfect measure of combat as described previously. We adjusted for age using birth-year cohorts. This was done, in part, because such grouping provided consistent identification of participants who provided data across an 8 year span (2001-2008). Misclassification of true demographic characteristics may have occurred, most likely resulting in the reported association being weaker than the true association.

As with all surveys, <100% of those invited to participate opt to participate. As described in the first paragraph of the Methods, the first enrollment panel had a participation rate of 36%. As a result, the Cohort may not be representative of the entire military or those who deploy. However, previous investigations suggest that the Cohort is a representative population of military personnel who report reliably with minimal health related tendency for enrollment, and showed little non-response bias at the first follow-up.[14,38-45]

We did not adjust for other important risk factors, including nonoccupational hazardous noise, such as recreational firearm use, and diabetes.[46] We were unable to ascertain nonoccupational hazardous noise exposure. Although diabetes is another risk factor for hearing loss, individuals with diabetes are not able to join the US military. That said, a small percentage will develop diabetes and continue to serve. A recent study conducted using Millennium Cohort data reported the occurrence of diabetes during an approximate 3 year follow-up was 3/1,000 person-years. Therefore, very few members of this cohort had diabetes and the likelihood that important confounding resulted from this condition is extremely low.[47]

Loss to follow-up represents another limitation, with 71% of subjects enrolled in 2001 completing the survey at either the

first or second follow-up. Although loss to follow-up may result in bias, we have previously investigated this possibility using statistical techniques for missing data and have found that it did not bias risk estimates for several key outcomes of this study, including posttraumatic stress disorder (PTSD), depression, and eating disorders.[39] We adjusted for multiple variables potentially associated with both the exposure and outcome. The potential remains though for residual confounding due to unmeasured variables or inaccurately measured variables meeting the criteria for confounding.

This study has multiple strengths, including a large sample size permitting subgroup analyses and detection of smaller associations with excellent power, and a longitudinal design that permits assessment of new-onset outcomes in relation to previously measured exposures. In addition, the study included a large proportion of National Guard/Reservists and followed subjects even after separation from the military, thereby providing an advantage over analyses based on electronic data for active-duty service members until the time of separation from the military. We assessed multiple relevant exposures, including combat deployment, and specifically combat-related head trauma and proximity to an explosive blast, smoking status, occupation requiring PPE, or exposures that involve routine contact with chemicals, among other factors.

In summary, these are the first analyses to our knowledge to define and quantify the substantial risk of new-onset hearing loss related to military combat-related exposures. We found that combat experience was associated with a 63% increased risk for hearing loss. In addition, we also identified that individuals who reported exposure to an explosive blast or had combat-related head trauma were much more likely to report hearing loss. This study also demonstrated the validity of self-reported hearing loss, when queried in the context of the Millennium Cohort Study, in defining this important health outcome. From a clinical perspective, the 6-fold increase in risk of hearing loss after combat-related head trauma deserves further attention. A multidisciplinary approach to treatment of patients with combat-related head trauma should take into account possible overlapping symptoms with blast-related comorbidities including PTSD, dizziness and imbalance, and speech and language problems, in order to identify and properly manage auditory system outcomes.[27,48] This may facilitate overall recovery, improve cognitive deficits, and result in better quality of life. Preventive strategies should include early detection and monitoring of hearing loss, based on pre-deployment and post-deployment audiograms, to inform clinical practice guidelines, as well as development of improved and more acceptable hearing protection, protective head gear, and possible identification of effective otoprotectants.

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14. ABSTRACT

To define the risk of hearing loss among military members in relation to their deployment experiences, data were drawn from the Millennium Cohort Study. Self-reported data and objective military service data were used to assess exposures and outcomes. Among all 48,540 participants, 7.5% self-reported new-onset hearing loss. Self-reported hearing loss showed moderate to substantial agreement (k = 0.57–0.69) with objective audiometric measures. New-onset hearing loss was associated with combat deployment (adjusted odds ratio [AOR] = 1.63, 95% confidence interval [CI] = 1.49–1.77). Among deployers, new-onset hearing loss was also associated with proximity to improvised explosive devices (AOR = 2.10, 95% CI = 1.62–2.73), and with experiencing a combat-related head injury (AOR = 6.88, 95% CI = 3.77–12.54). These findings have implications for health care and disability planning, as well as for prevention programs.

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